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ABSTRACT

Following recent tornadoes, terms of specially trained architectural and engineering faculty conducted onsite examinations and research of building damage. It was concluded that tornado damage to buildings is predictable. A trained architect or engineer can establish, before a tornado strikes, those portions of the building that will offer the greatest protection to the occupants. The characteristics of tornadoes are explained in text and illustrations. Case studies are given of three school buildings hit with different, intense tornadoes. The hazardous and protective elements of the buildings are identified, and the tornado shelter quality of portions of these buildings rated as primary or secondary shelter. The purpose of this brochure is to assist architects and engineers to design facilities that offer tornado protection, and administrators to identify the best available shelter space. (Author/MLF)

WHAT'S LEFT after a TORNADO

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introduction

Tornadoes strike indescriminately across the United States. They have caused damage in recent years from western Washington to New Jersey, from Florida and Texas to northern Minnesota and even into Ontario and Quebec. They occur in the plains, near bodies of water and even adjacent to high mountains. They hit small farm settlements, small towns and large urban areas.

Administrators of buildings should know the safest places in their buildings, the portions that would offer protection should it be hit by a tornado.

Following recent tornadoes, teams of specially trained architectural and engineering faculty conducted on-site examinations and research of building damage. It was concluded that *tornado damage to buildings is predictable*.

A trained architect or engineer can establish before a tornado strikes those portions of the building which will offer the greatest protection to the occupants.

Most buildings offer a significant amount of protection, usually enough to shelter the normal occupancy of the facility.

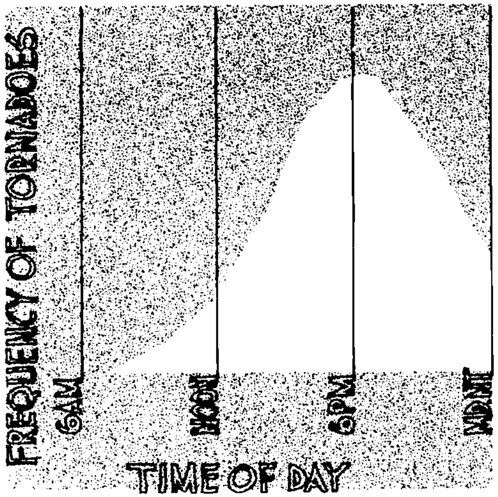
The purpose of this brochure is to share some of the findings of the researchers so that building designers and administrators might offer better protection to the occupants of their facilities.

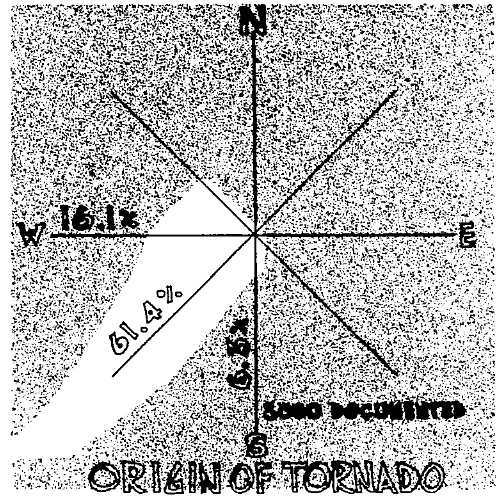
The findings are also applicable to building damage caused by hurricanes or other high winds.

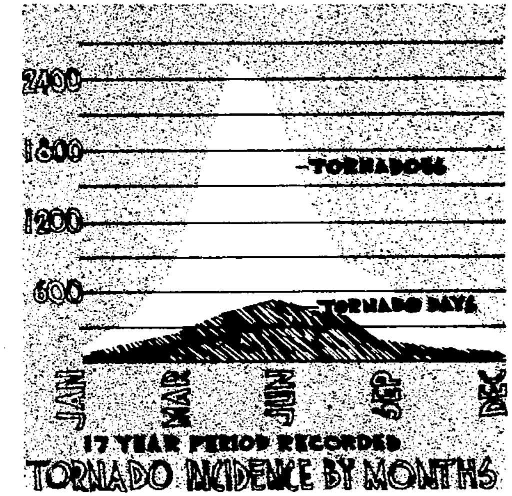
Architects and engineers should be able to use this information to design facilities which offer higher levels of protection against high winds.

The Institute for Disaster Research at Texas Tech University provided much of the substance of this brochure. Dr. Joseph Minor and Dr. Kishor Mehta of the Institute assisted in the brochure preparation and review.

This brochure would not have been possible without the willing assistance rendered by the architects and engineers of the various buildings. Similar assistance was provided by the beleaguered school administrators who desired that others learn from their experiences.

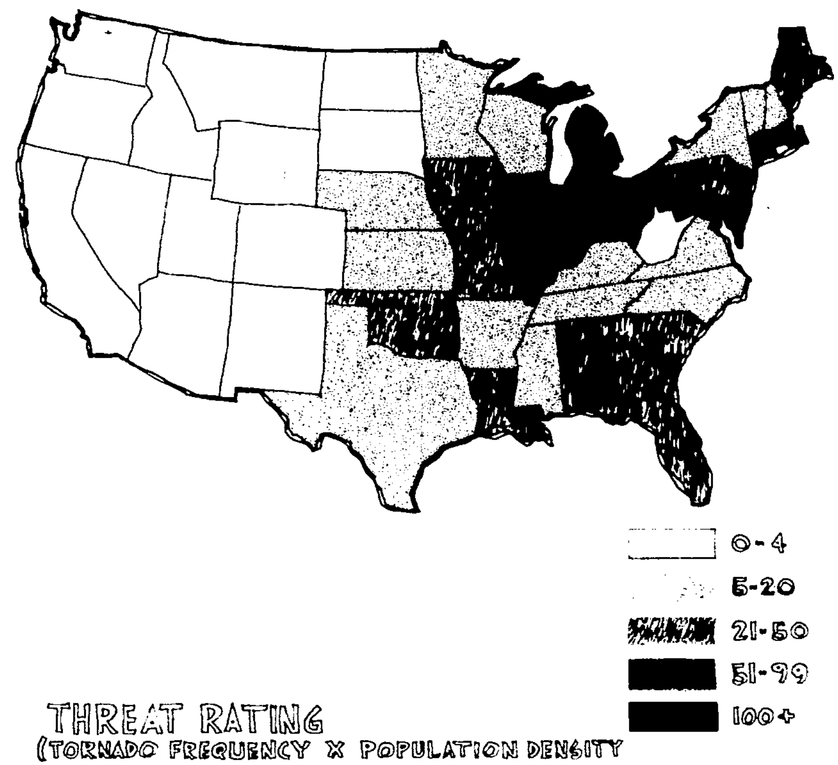






The National Weather Service defines a tornado as *a violently rotating column of air pendant from a thunderstorm cloud and touching the ground.*

From a local perspective, a tornado is the most destructive of all atmospheric generated happenings. In an average year, over 600 tornadoes hit various parts of the U.S. About half of them occur from April - June.



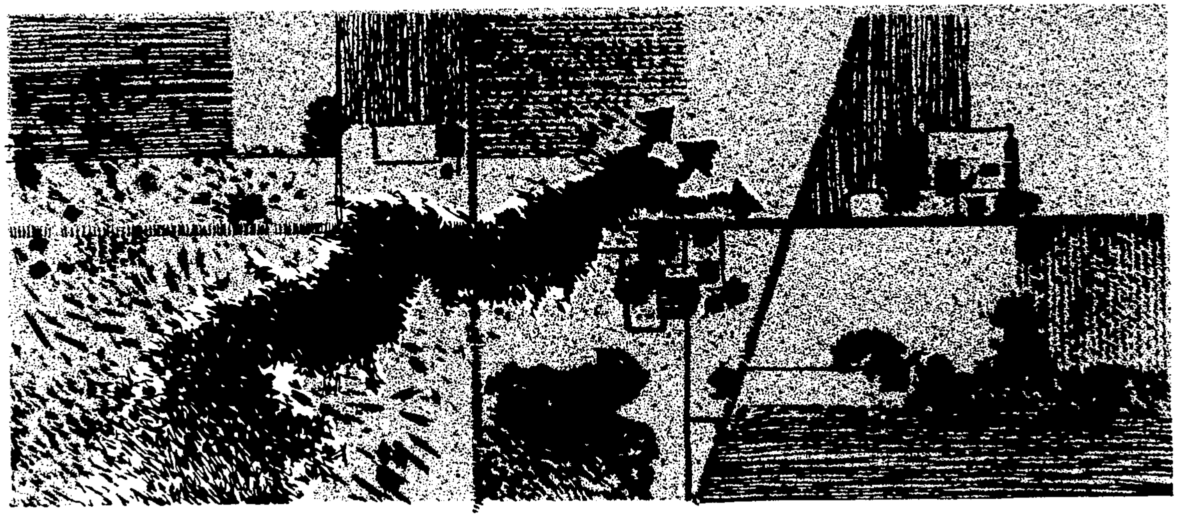
TORNADO CHARACTERISTICS

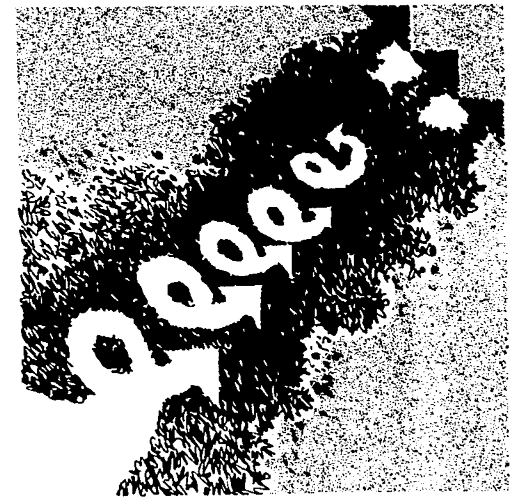
TIME OF DAY during which tornadoes are most likely to occur is mid-afternoon, between 3-7 P.M.

DIRECTION OF MOVEMENT is predominately from the southwest to the northeast. Tornadoes associated with hurricanes may move from an easterly direction. About 85% of all tornadoes (nationwide) come from the southwest plus or minus 45 degrees. Directions may vary significantly in local areas.

LENGTH OF PATH averages 4 miles but some have exceeded 100 miles.

WIDTH OF PATH averages 300-400 yards but may reach up to 1 mile.



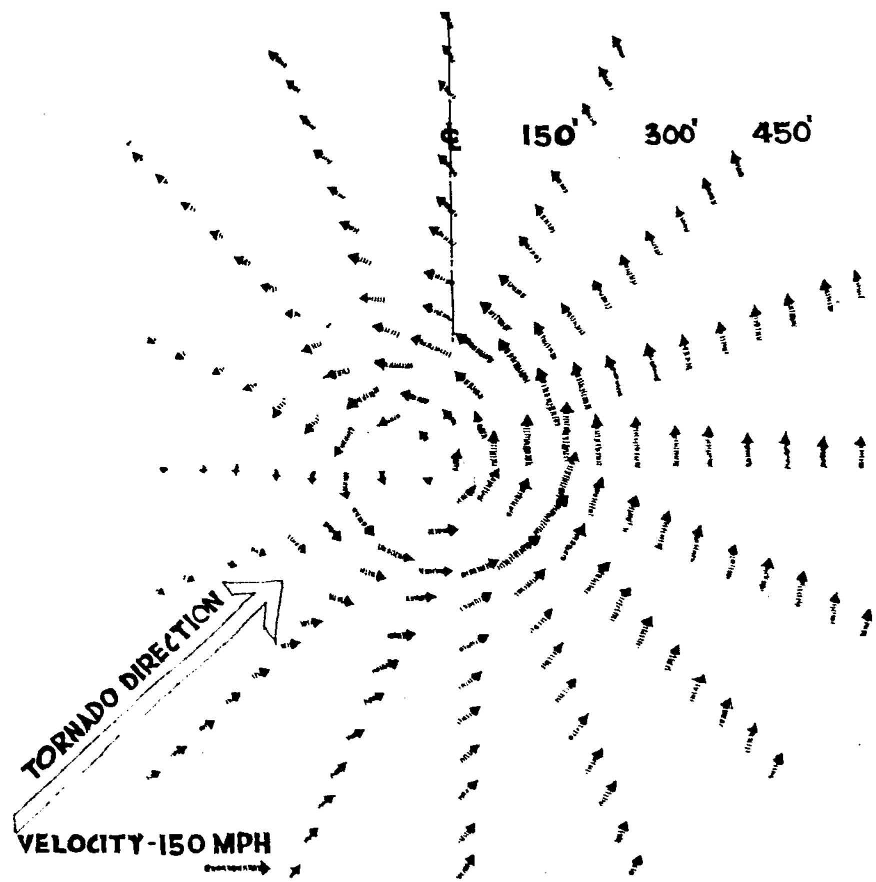


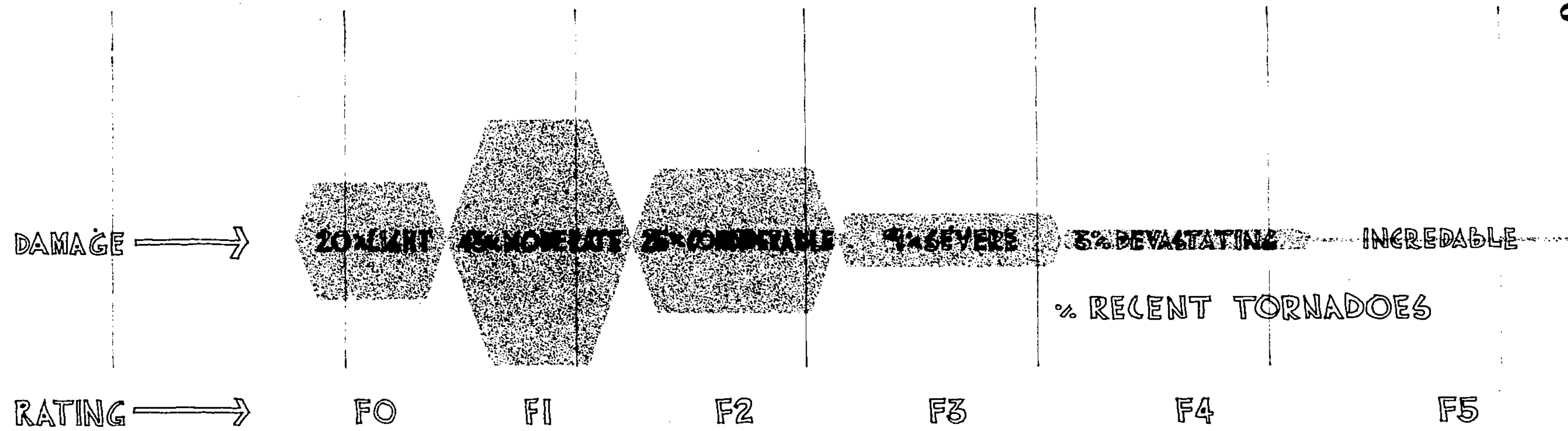
SPEED OF TRAVEL (TRANSLATIONAL) averages from 25 to 40 mph, but speeds from 0 to 70 mph have been recorded.

SPEED OF TRAVEL (ROTATIONAL) is assumed to be symmetrical. The maximum rotational velocity occurs at the edge of the tornado core. It reduces rapidly as the distance from the edge increases.

A simplified example tornado is shown graphically combining the translational and rotational wind speeds. The drawing is based upon a maximum rotational velocity of 110 mph at 150 feet from the funnel's center. a 40 mph translational velocity is assumed. Therefore a maximum combined velocity is 150 mph. This example tornado *is more severe than 85% of all tornadoes*.

Note the largest velocities are found on the right side of this counter-clockwise turning tornado. Over 99% of all tornadoes turn in this manner.



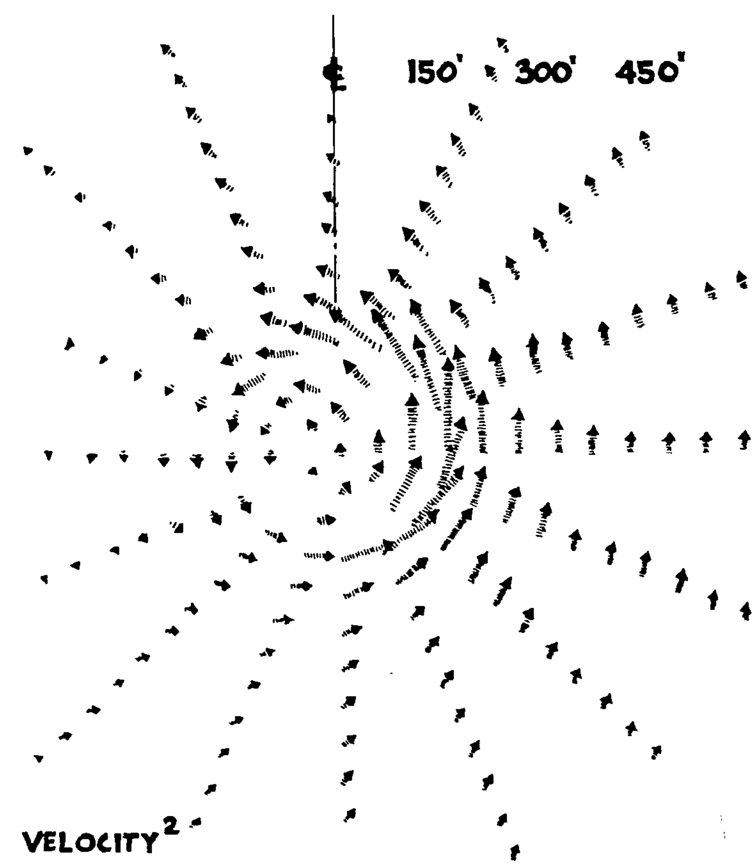


1.03

THE INTENSITY OF DAMAGE from a tornado is related to the windspeed (assuming consistent building construction). The *F rating* scale has been developed by Dr. T. Theodore Fujita. It is based upon trained meteorologist's evaluation of damage following a tornado. 88% of recent tornadoes have been rated F0, F1 or F2.

Building damage is caused by the buildup of pressure caused when the high wind effects a building surface. this pressure is related to *wind velocity squared*.

The *damage potential* of the same 85th percentile tornado is shown graphically. Note that the greatest damage potential is on the right side of the tornado. If the storm came from the southwest, the maximum damage potential would be from the south.



Tornadoes cause threats to life in buildings due to a combination of effects which happen at almost the same time. Expert interpretations of building damage yields the following tornado effects *in order of importance*.

EXTREME WINDS

Even the most modern building codes do not require buildings to withstand the winds of a tornado. Many buildings have been erected without the requirement to meet any building code. As a result, it is not surprising to see that almost all buildings are no match for a tornado.

These extreme winds are almost always rotating in a counter-clockwise direction. It should be presumed that the entire building may be engulfed by the fury of the storm.

The wind speed increases with height, causing maximum damage potential on the top floor of a building.

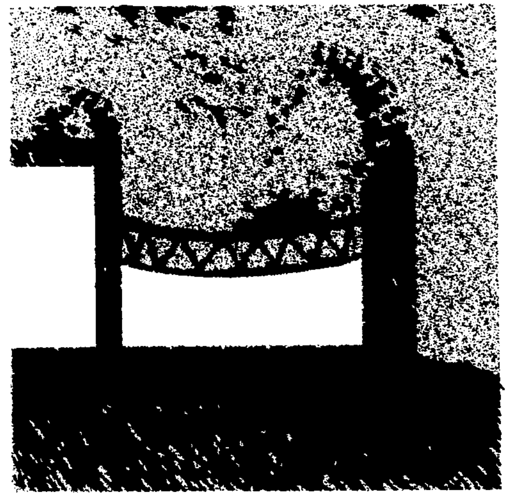
WINDWARD WALLS usually face south and west. However, east and even north walls can be windward depending on the size and location of the storm and the building. The glass, bricks and block that make up these walls will be blown into the interior of the building.

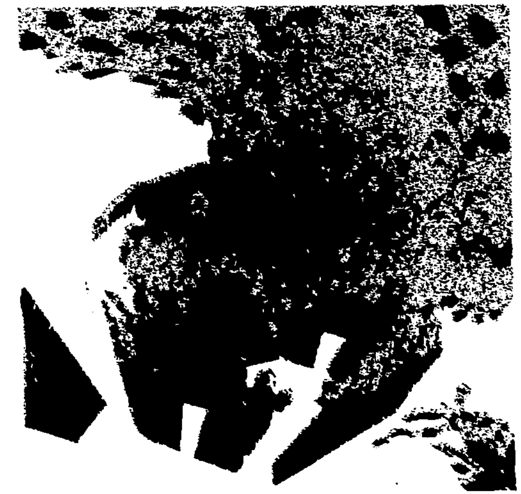
LEEWARD WALLS usually face north and east. The winds tend to cause the leeward or back sides to be pulled out. The pressures are much smaller than the windward side. The net result is therefore less damage to the leeward walls. The windows on these walls usually blow *out*.

Severe damage can occur to the leeward walls if the windward walls are penetrated. This *filling the balloon* happening adds a powerful force to blow out the back walls.

ROOFS, especially flat roofs and those with slight slope tend to be lifted up and carried away. Overhangs and eaves on the windward side are the most vulnerable and compound the uplift problem. Roofs with steep slopes are somewhat less vulnerable to uplift but can be blown sideways.

Lightweight roofing materials (gravel, wood, insulation, shingles and steel deck) are often lifted and thrown hundreds of feet in all directions by the tornado. The weight of concrete roofs tends to resist uplift.





MISSILES

The high speed whirling winds can make almost anything (or anyone) into a missle. Automobiles, busses and tractor trailers can be tumbled about. Portions of buildings become airborne at high speed. The exterior wall materials on the windward sides often become missiles thrown into the building interior.

Missiles move much faster in the horizontal direction than in the vertical direction. Also, many more missiles are moving horizontally. Therefore, it is more serious to have a wall missing than a roof insofar as missile protection is concerned.

Missiles are a majot threat to life. Fortunately, they are usually stopped by substantial, somewhat massive interior partitions. Buildings without such interior partitions can be death traps.

COLLAPSE

Portions of buildings may fail during the storm and collapse upon other spaces in a building. Chimneys collapse frequently, spilling their massive debris onto the roof of adjacent spaces.

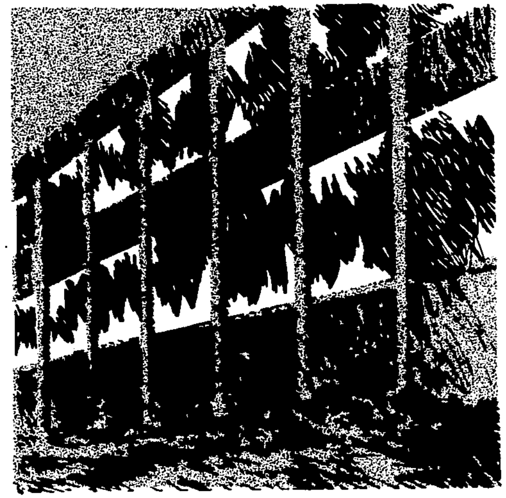
Higher portions of buildings may collapse onto adjacent lower spaces adding an extreme load to an already weakened roof system.

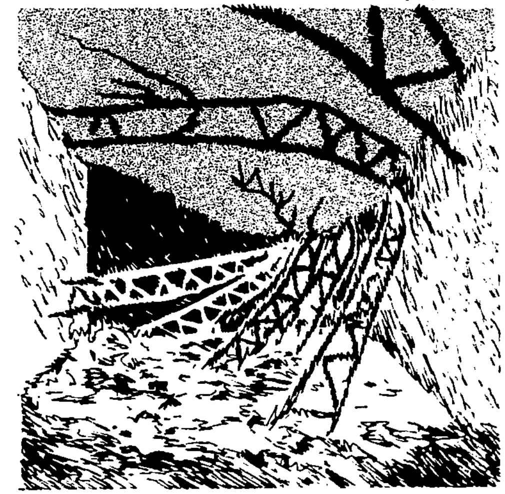
PRESSURE DIFFERENCE

A tornado is a very localized low pressure storm in an overall low pressure system. The atmospheric pressure inside a building exceeds the outside pressure causing the building to tend to *explode*. Little is known about the magnitude of the pressure drop, since operating barographs have rarely survived a tornado.

Building *explosions* due to atmospheric pressure difference have probably been greatly overstated. Almost all damage can be explained from the extreme winds, missiles and collapse.

However, since the pressure difference does occur, it is proper to open windows, especially on the leeward sides to help equalize the pressures.





2.03

The somewhat predictable action of the winds, missiles, collapsing elements and pressure difference makes possible the identification and design of protected spaces for human occupancy. These *best protected spaces can be identified and should be occupied during a storm.* People should not be randomly distributed throughout a building hoping that the tornado misses that spot. They should move to pre-selected locations offering the best-available protection.

These comments should not be interpreted to mean that the best available shelter in all buildings are good enough to protect life. Some single-story lightweight buildings, especially modular houses and classrooms should be evacuated.

POTENTIALLY HAZARDOUS ELEMENTS

Every building contains some very vulnerable elements that can not be counted upon to effectively withstand a tornado. Portions of buildings which contain one or more of these elements should be avoided whenever possible. *They are presented in order of importance for life safety.*

WINDOWS are no match for the extreme winds or missiles of a tornado. They usually break into many jagged pieces and are blown into interior spaces from the windward awlls. Tempered glass will break into thousands of small, cube-like pieces.

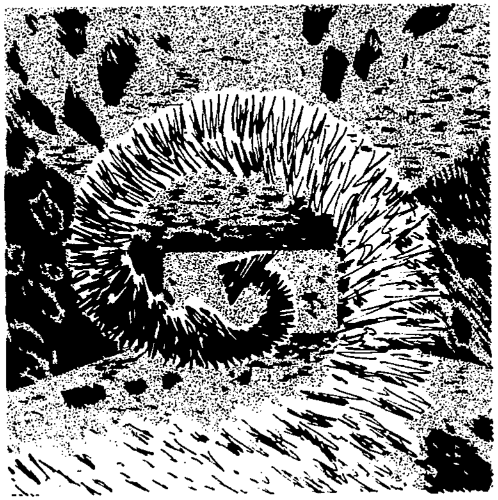
Windows in interior spaces also break, usually from missiles.

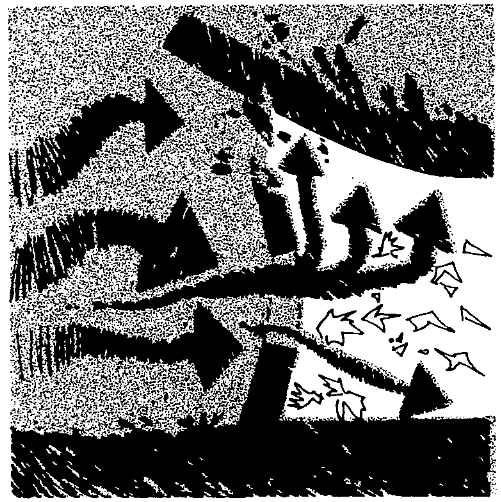
Plastics (acrylic or polycarbonate) are more resistant to impact than glass but may pop out in large panes.

Windows at the ends of corridors are very dangerous, particularly facing south and west. The windows will probably be blown down the corridor.

LONG SPAN rooms almost always have high ceilings. The exterior walls are therefore much higher than the typical one story wall. This higher wall often collapses. Sometimes it blows into the long span. Roofs depending on the wall for support then fall in.

Building administrators must resist the temptation to gather large segments of the building population into large spaces to facilitate control. *Often these large spaces are the scenes of maximum damage. If maximum damage occurs where large groups of people are present, major loss of life could occur.*





Lightweight roofs such as steel deck, wood plank and plywood will usually be lifted up and partially carried away with some of the roof debris falling into the room below. The roof opening then allows other flying debris to be thrown into the interior space.

Heavier roofs, especially precast concrete planks may lift up and move slightly and then return down but not always exactly to the same supporting place. If the support has collapsed, the heavy roof may fall onto the floor below causing almost certain fatalities to anyone below.

WIND TUNNELS occur in unprotected corridors facing the direction of oncoming winds which is usually south or west. Openings in these directions allow the winds to penetrate the exterior and roar into interior spaces. The winds apparently occupy almost the entire volume of a wind tunnel. Debris marks cover the entire height of the walls.

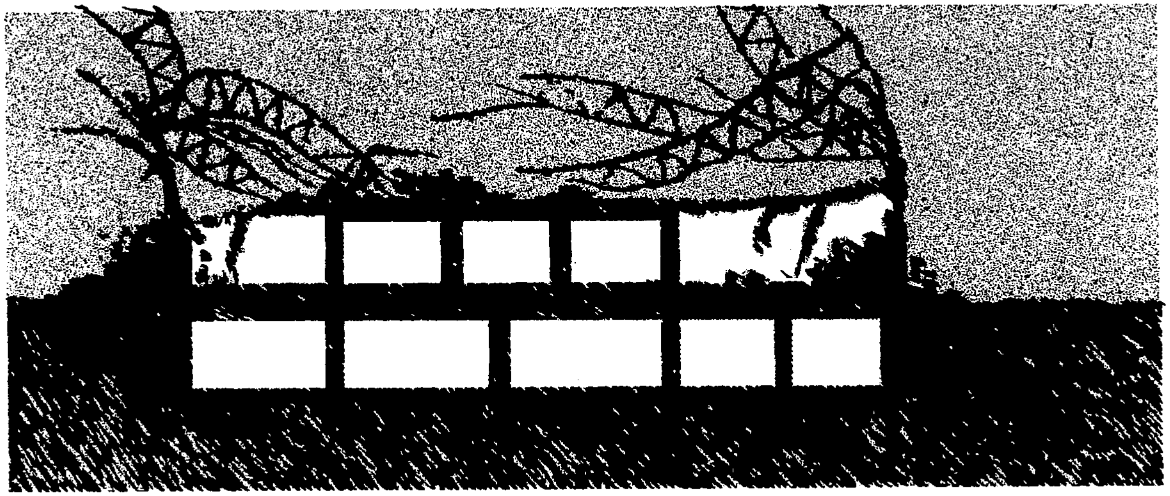
If the entrance is baffled with a solid, massive wall, this effect is much less serious.

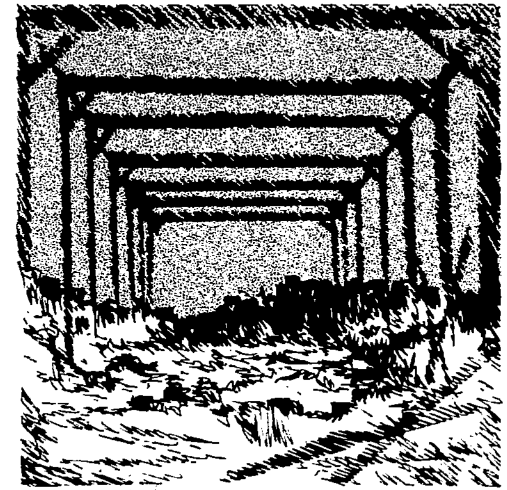
WINDWARD SIDE walls (usually south and west) receive the full fury of the winds. Windows on these sides should be assumed to be broken and blown into the rooms on the windward side. This often results in filling the room with additional air which aids in raising the roof.

LOAD-BEARING WALLS are the sole support for floors or roofs above. If the winds cause the supporting wall to fail, part or all of the roof or floor will collapse. The most dangerous locations are usually along the south and west sides and at all corners of a building.

Masonry construction is not immune to wall collapse. Most masonry walls are *not* vertically reinforced and can fail when high horizontal forces such as winds or earthquakes occur.

Masonry exterior walls in excess of 10 feet in height are potential hazardous elements.





2.05

PROTECTIVE ELEMENTS

Each building contains a number of elements that assist in the location of the safest spaces for occupancy. The best spaces are those that combine two or more of these protective elements while having none of the potentially hazardous elements. The protective elements are presented *in order of importance for life safety.*

The LOWEST FLOOR is usually the safest. The upper floors receive the full fury of the winds. In some cases the funnel hovers near the ground but is low enough to hit the upper floors only. Below ground space is almost always the safest location for shelter. If the building has but one floor and no basement, seek out the remaining protective elements.

INTERIOR SPACES often form a protected core. A room that is completely interior protects against missiles and the *wind tunnel* effect. The best interior partitions are somewhat massive, fit tight to the roof or floor structure above and are securely fastened to the floor or roof. Avoid interior partitions that contain windows.

SHORT SPANS on the roof or floor structure usually remain intact. This is due to the fact that the short span limits the amount of uplift caused by the winds and therefore increases the chance that the roof or floor will remain intact. While short structural spans are best, small rooms, even though the walls are not supporting the roof are usually quite safe. If the roof rises and collapses, the interior walls may *become* supporting walls and thereby protect the occupants.

FRAMED CONSTRUCTION usually remains intact. Any structural system that is rigidly framed together is superior to load-bearing walls. Poured-in-place reinforced concrete usually remains after the storm. Rigidly connected steel frames are usually still in place after the tornado passes. However, in both of these cases the floor or roof system must be securely connected to the supports. Gravity connection of roof deck to frame is not adequate. Generally, the heavier the floor or roof system, the more resistant it is to lifting and removal.

The three school buildings selected for examination in this brochure were picked for the following reasons:

a. All were hit with different, but very intense tornadoes.
b. All had to be partially or totally destroyed due to the extent of the damage.
c. All were relatively new structures, designed by different architects and engineers to national building codes.
d. The three structures varied in size, age and type of construction.

The building damage was examined by teams of specially trained architectural and engineering faculty, the building administrators and the responsible architectural offices.

The best-available shelter in the buildings is based upon three sources of information, *in order of importance;*

a. those in the building during the tornado.
b. building examinations by architects and engineers.
c. aerial photographs taken shortly after the storm.

The tornado shelter quality of portions of these buildings is divided into two categories. *PRIMARY SHELTER is the best available in that building during the storm.*

SECONDARY SHELTER locates those additional spaces which would have offered protection (possibly with some injuries).

Hopefully, these experiences will assist building designers and administrators to accurately locate *what's left after a tornado* before it strikes.

These experiences should assist architects and engineers to design facilities which offer the occupants excellent tornado protection at little or no additional cost.

MEADOWLAWN ELEMENTARY SCHOOL

MONTICELLO, INDIANA

Building population: *540 including staff*
None in building during storm.

Tornado direction: *from southwest*

intensity: *F3*

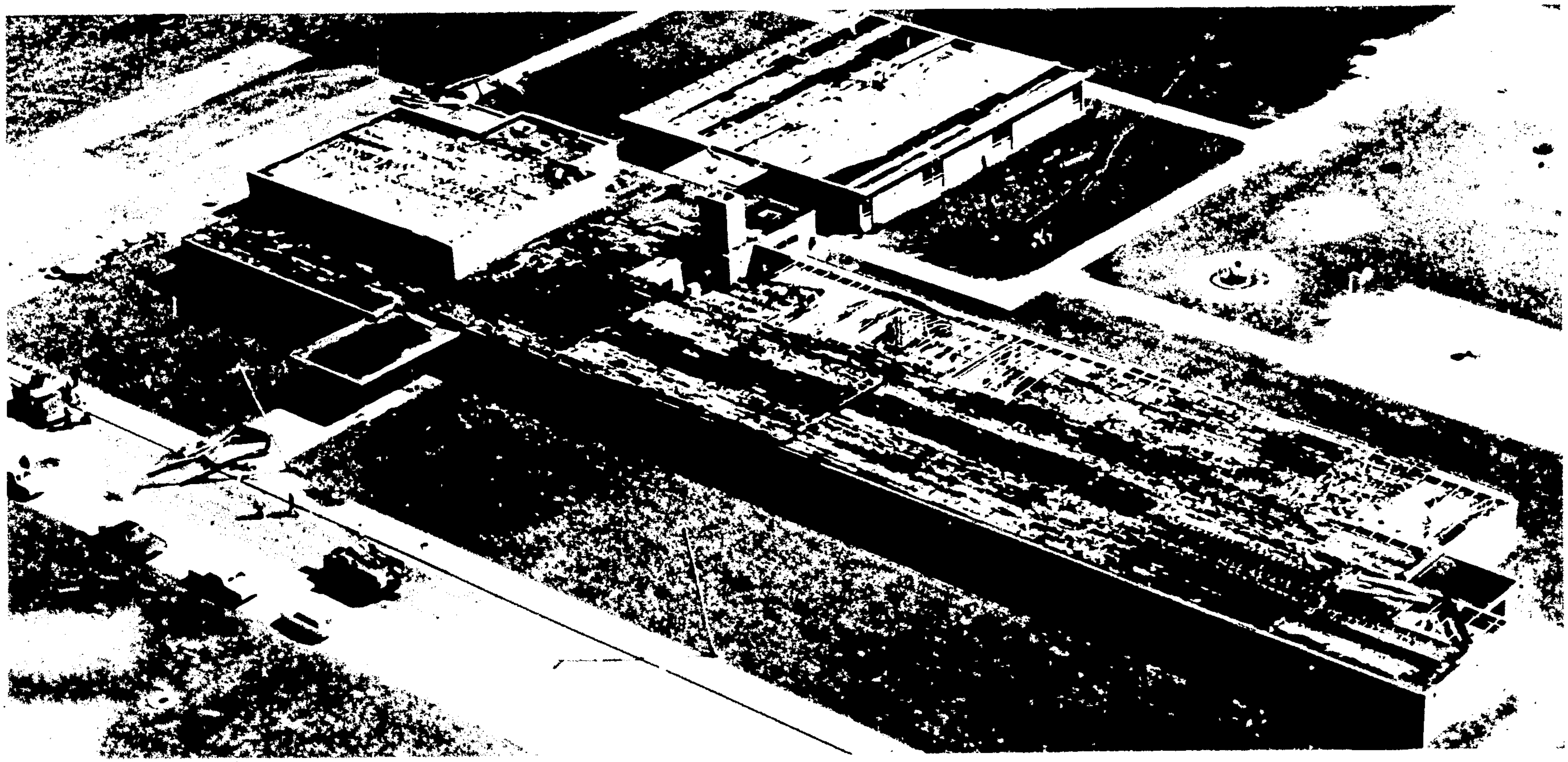
wind speed: *120 - 140 mph*

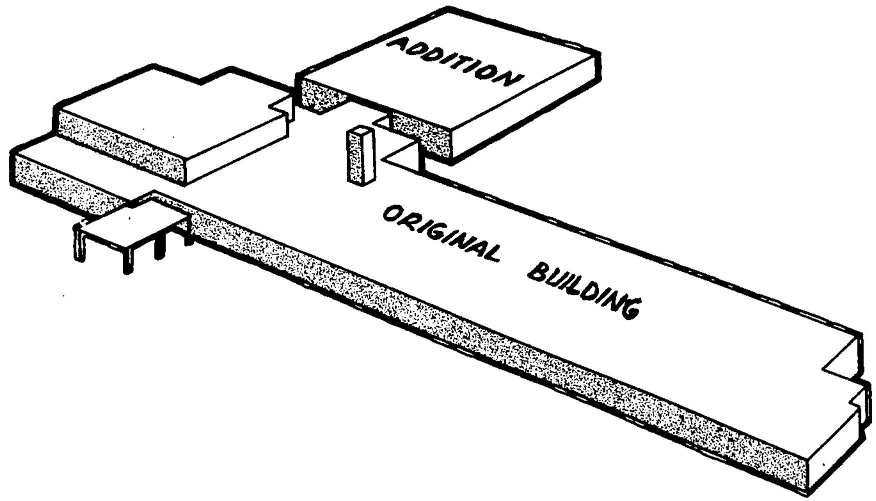
time: *5:16 P.M.*

The Meadowlawn Elementary School is typical of thousands of educational facilities built in the 1960's. The single-story, no basement school is located on the southwest edge of Monticello, Indiana. Conscious of the danger of tornadoes and aware of an approaching severe weather system, the school administration conducted a tornado drill on the morning of April 3, 1974.

Fortunately, the storm hit after school hours, but had it hit when fully occupied, the occupants knew in advance the location of the best-available shelter in the building.

3.02





CONSTRUCTION

ORIGINAL BUILDING
- exterior walls: *glass and metal curtain wall. End walls; 4" brick, 8" block.*
- interior walls: *plaster on metal studs. Block in (multipurpose and boiler rooms).*
- roof system: *steel frame. Steel open-web joists with metal decking and insulation.*

ADDITION
- exterior walls: *non-loadbearing 4" brick, 8" block, minimal glass.*
- interior walls: *same as original building*
- roof system: *same as original building*

TORNADO DAMAGE

HAZARDOUS ELEMENTS

Unrepairable damage occurred to the original classroom wing when the south exterior walls failed. The *WINDOWS* blew into all of the *WINDWARD SIDE* classrooms. All south and west windows were broken. The wind entered these rooms causing a ballooning effect. Some of the metal roof deck was uplifted, landing throughout an open field northeast of the school.

The winds blew into the west facing classrooms, causing the furniture to be thrown around and to settle into cone-like piles in the center of the rooms.

The glass in the unbaffled south entrance blew throughout the corridor causing a *WIND TUNNEL.*

The winds in this corridor caused some of the roof decking to uplift.

The original 12 classrooms and library were demolished. The boiler room, multi-purpose room, offices and the 6 classroom addition were repairable.

PROTECTIVE ELEMENTS

The *STEEL FRAME* remained intact.

The *INTERIOR PARTITIONS* stopped incoming missiles from reaching adjacent rooms or corridors.

North and East classrooms received little damage.

Roof fans lifted off the multipurpose room helping the pressure difference to equalize without serious damage.

The gymnasiun did not collapse. This is partially due to the fact that it is located in the northeast corner of the building.

The office spaces, workroom, lockers and storage spaces were undamaged due to *SHORT SPANS*.

COMMENTS

"The important thing as far as I'm concerned in reference to the structure of this building is that we had two support walls going down the middle. Now, in my opinion, if we would have had some form of open-type construction such as I've seen with open concept building, I'm afraid that we would have had a severe loss of kids if we had been in the building.

We would have had no major injury and we're talking about probably 400 kids along this east-west corridor."

\- PRINCIPAL

"We are aware of the fact that Indiana is prone to tornadoes. Therefore each year we formulate plans, and I might say that in the morning of April 3, all of the buildings within the Twin Lakes School Corporation conducted tornado drills. We had quite a sophisticated plan for placing students in what we feel are the safest areas within the school.

As a result of this tornado, we have been able to go back into the buildings that were hit by the storm and evaluate the tornado drills that we have. In most cases we have found areas that we had earlier identified asbeing safe areas appear that they would have been safe had the tornado hit during the school day, with a couple of exceptions."

\- SUPERINTENDENT OF SCHOOLS

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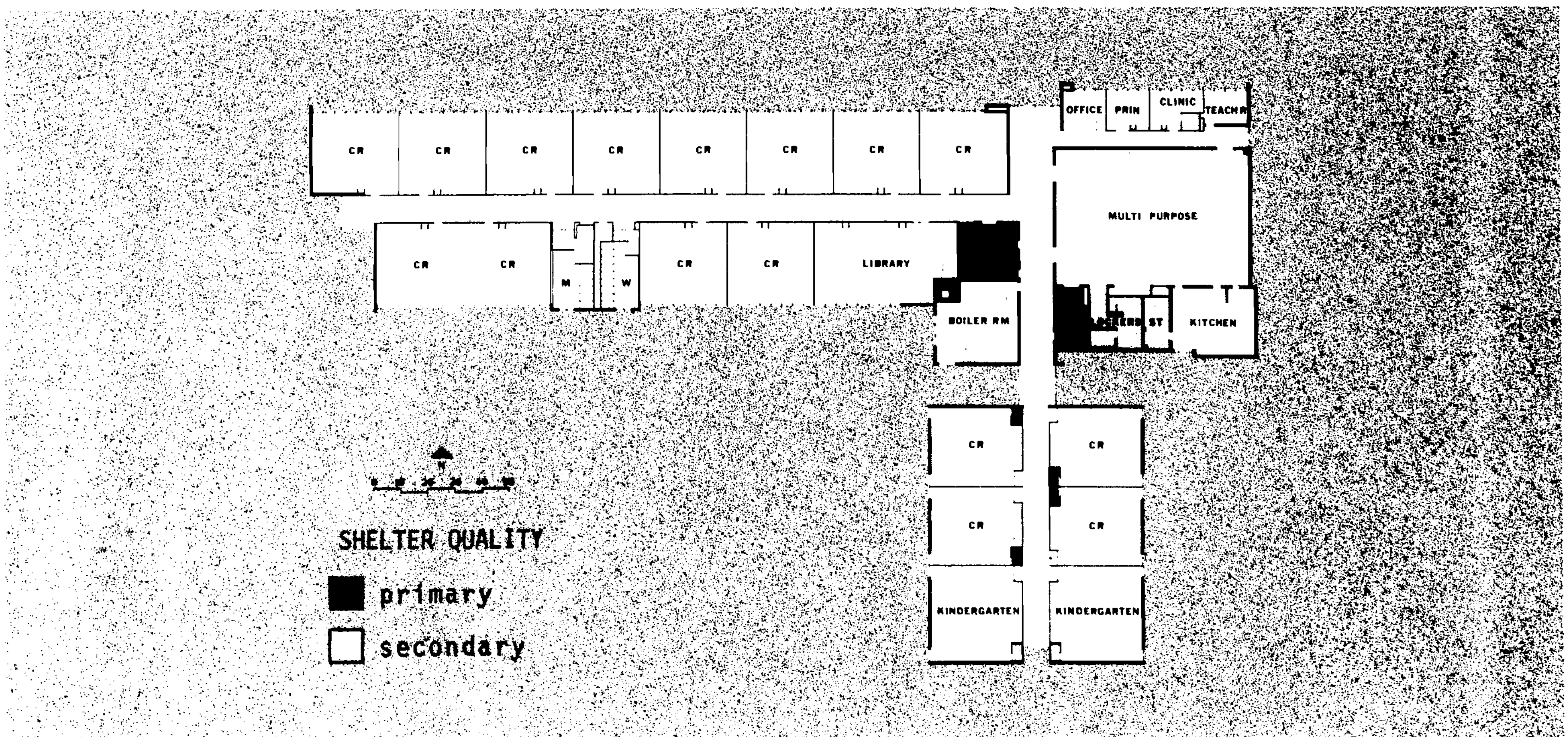


MONROE CENTRAL SCHOOL

PARKER, INDIANA

Building population:	*690 including staff* *14 staff during tornado*
Tornado direction:	*from south southwest*
intensity:	*F3*
wind speed:	*110 - 130 mph*
time:	*3:46 P.M.*

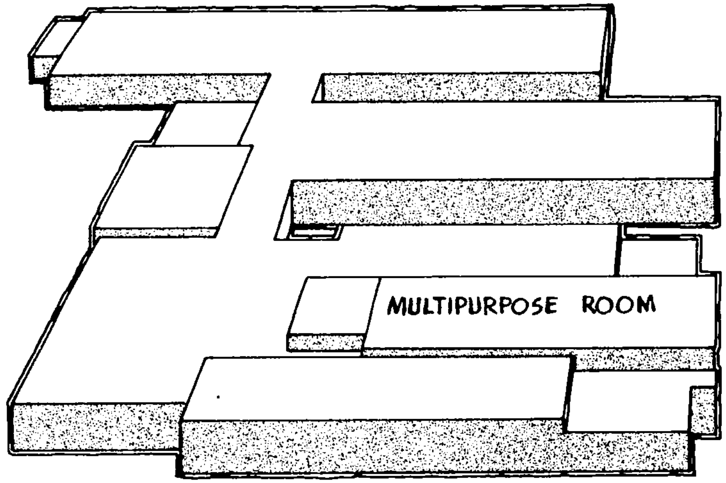
This single-story, no basement, slab-on-grade school was located in rural eastern Indiana. It contained a junior and senior high school plus the administrative offices of the school corporation (district).

The storm hit 30 minutes after the school dismissal and caught the remaining staff by surprise.

Fortunately, a tornado drill was conducted on April 2, 1974 and the staff went quickly to a preselected spot and escaped with slight injuries.

The building was so badly damaged that it was deemed a total loss and was completely demolished.

3.05



CONSTRUCTION

MULTIPURPOSE ROOM
- exterior walls: *4" brick, 8" concrete block.*
- structure: *rigid steel frame, load-bearing south end wall, 2" pressed fiber board roof deck on steel tees.*

MAJORITY OF BUILDING
- exterior walls: *glass and metal curtain wall, 4" brick, 8" block*
- interior walls: *8" block*
- structure: *precast concrete frame, precast concrete hollow-core roof plank. (not rigidly connected)*

TORNADO DAMAGE

The tornado center passed slightly to the right of the center of the building, but inflicted major damage to all three wings. The enclosure walls failed allowing the winds to enter interior spaces, uplifting roofs and tossing debris throughout the building.

HAZARDOUS ELEMENTS

(Multipurpose Room)

The *WINDWARD* (south) high *LOAD-BEARING MASONRY WALL* of this *LONG SPAN* room collapsed and blew the brick and concrete block throughout the entire room.

The winds entered the room causing a ballooning effect. The lightweight roof deck was completely removed. Some of the deck and the steel bulb tees fell onto the floor. The remainder blew onto adjacent roofs and open spaces.

The high leeward (north) wall of the multipurpose room *COLLAPSED* onto the locker room roof below.

HAZARDOUS ELEMENTS

(Majority of building)

The winds blew into the building from the south and east. The *WINDWARD* (east) *GLASS CURTAIN WALLS* blew in allowing a ballooning effect. The *LOAD-BEARING* end walls blew out from this effect. The precast concrete roof planks were uplifted. Some fell back into the rooms, others blew on top of the remaining roof. The north-south corridors became *WIND TUNNELS* throughout their entire length.

Automobiles were rolled and tumbled from the adjacent south parking lot against the building.

PROTECTIVE ELEMENTS

The completely *INTERIOR SPACES* remained intact offering protection against incoming missiles such as glass, brick, gravel and block. This was particularly true of the *SHORT SPANS* or smaller spaces such as toilet rooms, work rooms and storage spaces. Rooms on the leeward (north) side received least damage. Only one north window was broken. The *STRUCTURAL FRAME* remained intact. However, the roof deck was not rigidly connected to these frames and for the most part depended upon their weight to resist wind uplift. The *HEAVY CONCRETE ROOF* remained intact over most of the building.

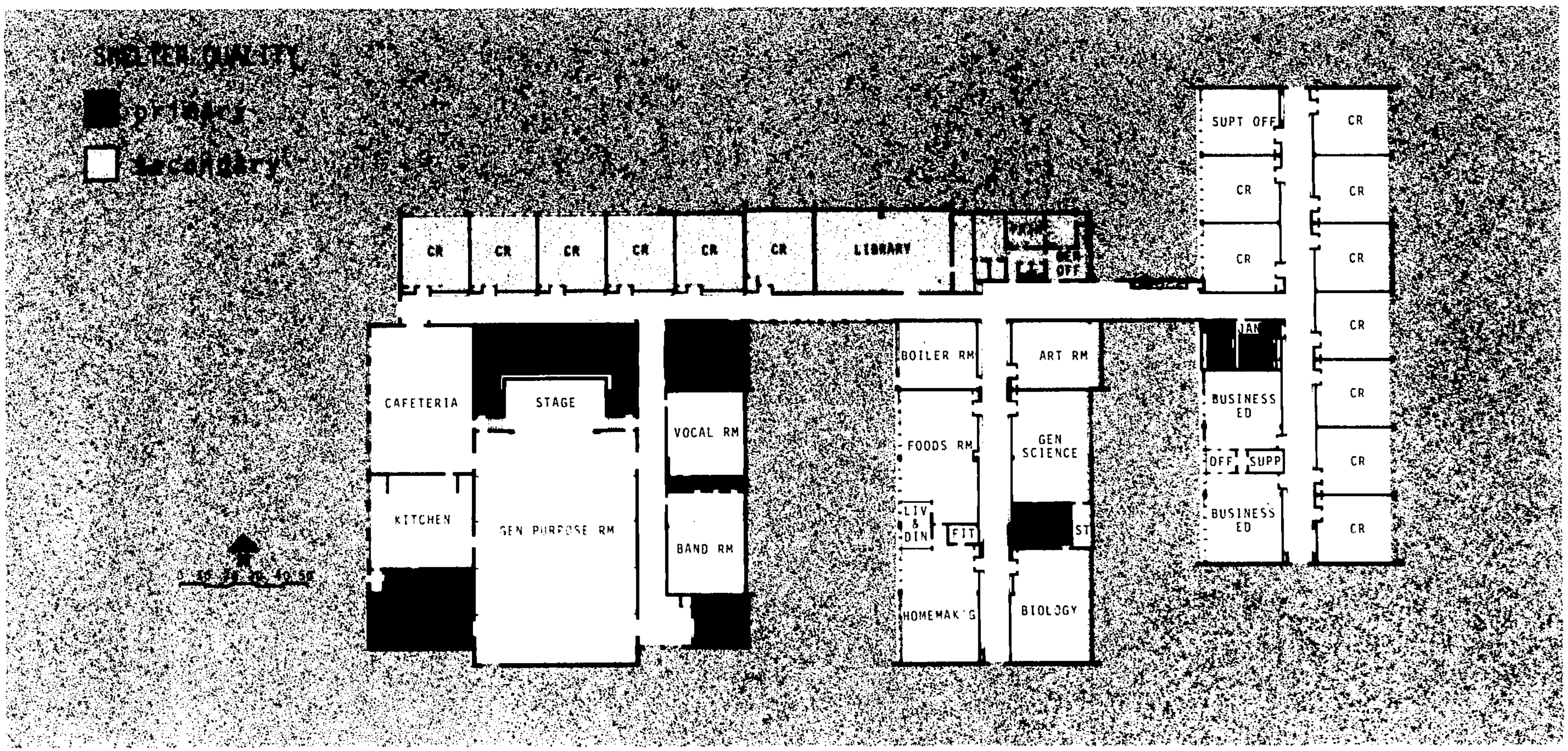
3.07

COMMENTS

"Those in the building had about 2 or 3 minutes prior warning before the tornado struck. I walked about 50 feet and was approaching my car. I heard this terrific noise. It sounded like 50 jet airplanes treetop high. I glanced over my shoulder to the southwest and saw this mammoth black cloud rapidly approaching. I froze for an instant. Then, realizing it was a tornado, I ran back into the building yelling and shouting to others of the approaching danger.

We took cover in the north-south corridor beside the boiler room against a west wall lined with lockers. We all kneeled side by side in a line with our hands over our head for protection. The corridor darkened, doors on the south end of the corridor banged, opened and closed and a wastebasket blew from an east room west across the corridor into another room facing west. There was some glass breakage. The damage didn't appear to be too great. At the conclusion of this there was a period of calmness, I would say 2 - 5 seconds, and then the storm really hit. Debris was flying down the corridor. This consisted of mud, sticks, stones, glass, plastering, pieces of brick and cement block. Everyone ducked their head just a little bit farther when this occured. The terrific suction moved us in the corridor a short distance. 1 custodian was being sucked around a corner and he grabbed for others to keep from being blown away". - SUPERINTENDENT OF SCHOOLS

3.08



XENIA SENIOR HIGH SCHOOL

XENIA, OHIO

Building population:	*1450 including staff* *12 students, 3 staff in storm.*
Tornado direction:	*from southwest*
intensity:	*F5*
wind speed:	*140 - 160 mph*
time:	*4:45 P.M.*

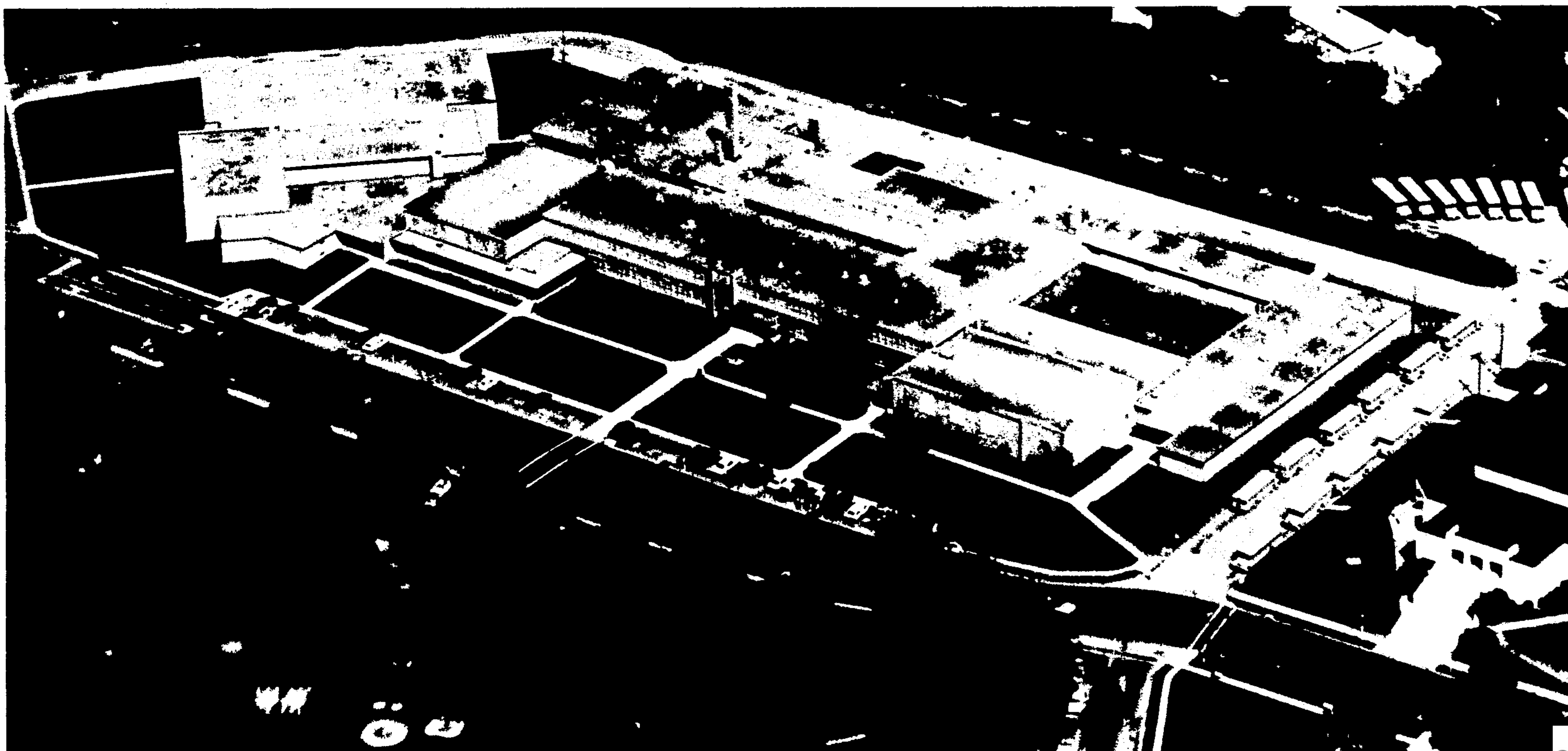
This two-story, no basement, slab-on-grade school was located on the near north side of Xenia, Ohio. It faced Shawnee Park to the west.

The massive storm hit 1 hour and 45 minutes after school dismissal. It was spotted by a student who was leaving the school. She alerted the drama students who were rehearsing in the auditorium. The students ran and dove for shelter in a nearby corridor.

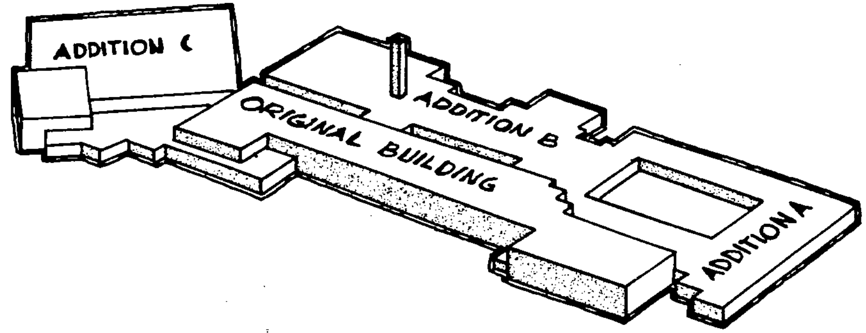
The storm passed directly over the school. 2 school busses came to rest on the stage where the students were rehearsing. Some of the students were treated at a nearby hospital for injuries.

The building was unsafe to enter and was demolished.

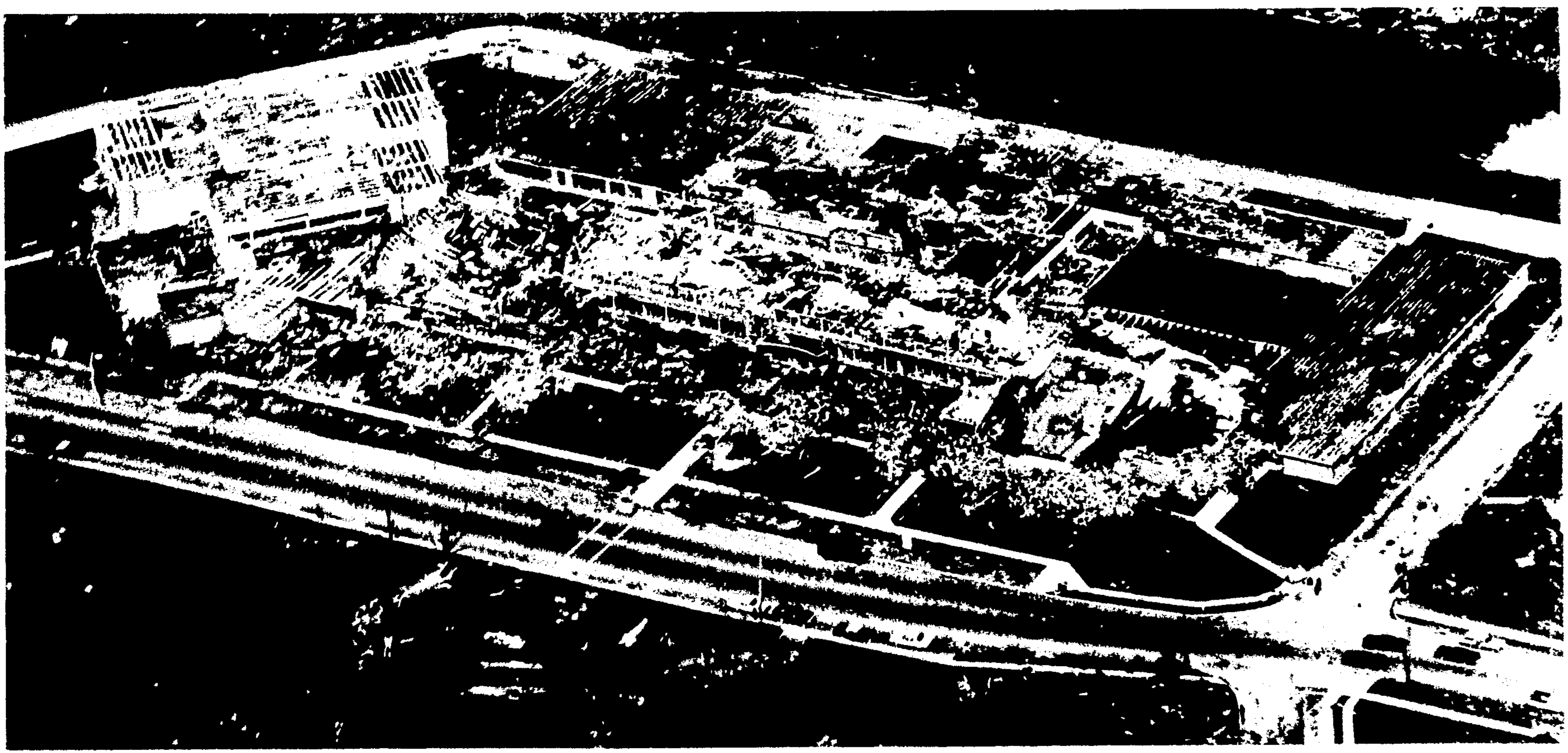
3.09



CONSTRUCTION



structure: *lightweight steel frame, open-web steel joists, 2" gypsum roof deck (original building & addition B)*
loadbearing masonry walls, hollow core precast concrete roof planks (addition A)
precast concrete frame, double tee floor/roof beams (addition C)
loadbearing masonry wall, precast concrete tee beams (girl's gym)
loadbearing masonry walls, steel trusses (auditorium & boy's gym)



TORNADO DAMAGE

The tornado passed directly over the school. It engulfed the entire building plus the adjacent fieldhouse to the south.

The enclosure walls failed on the west and south sides allowing the winds to enter the building. The roofs collapsed over the 3 large spans; auditorium, boy's gym and girl's gym. The lightweight roof over the original 2-story building was removed.

HAZARDOUS ELEMENTS

All *WINDOWS* on the *WINDWARD SIDES* (west and south) were blown into the interior. The high single-story, *LOADBEARING MASONRY WALLS* of the *LONG SPAN* rooms failed, allowing the roofs to fall in. The unbaffled west entrances allowed the east-west corridors to become *WIND TUNNELS*.

Debris from nearby homes, vehicles and the park became *MISSILES* which hit and entered the school.

The 46' high masonry chimney *COLLAPSED*. A non-loadbearing second-floor wall on the leeward (north) side *COLLAPSED* onto a lower roof.

PROTECTIVE ELEMENTS

The only portion to offer shelter in the original building was the *LOWEST FLOOR* (first floor). The completely *INTERIOR SPACES* remained intact, especially the *SMALLER SPACES*.

Most of the corridors which were perpendicular to the storm path offered considerable protection.

The concrete *STRUCTURAL FRAME* of addition C remained intact. As a result, interior portions of the second floor provided shelter for some custodians.

The *HEAVY CONCRETE ROOF* remained in place wherever the supports were rigid frames. It also remained intact in addition A with its loadbearing walls.

The concrete block interior partitions stopped incoming missiles from reaching adjacent interior spaces.

As a result of combinations of these elements, considerable shelter space existed in this school which received a direct hit from a most intense tornado. This shelter existed in scattered locations throughout the building.

COMMENTS

" The cast had just done the big dance number from the show. They had done a sloppy job and I was just getting ready to tell them to do it again when a girl yelled, 'Hey, you want to see a tornado? There's a funnel cloud outside'. I came very close to telling every one to forget it and do the dance again. That would have been a fatal mistake.

Instead, I jumped off the stage and told everyone to follow me so that we could get a view of it. We ran out the front doors of the school nearest the auditorium. It looked like a lot of dirt or smoke swirling around. We couldn't see anything that looked like a clearly defined funnel cloud. We were looking out at the park across from the school. The mass of wind, dirt and debris was somewhere, I would say, between 100 and 200 yards away. Cars parked in front of the school started to bounce around a bit from the force of the winds. It was really beyond belief.

Someone said we'd better take cover, so we turned around and ran from the hallway we were in into the center hall that ran north and south. Before we could reach the center hall, the lights went out.

I only opened my eyes a couple of times. When I did, I saw large pieces of dirt and wood flying through the air. Lockers clanged open and shut and several sections of lockers were actually pulled from the wall and thrown onto the floor. One section barely missed some of my students when it came out of the wall.

I was sitting directly across from one of the restrooms and a metal door kept flying open and shut constantly during the time that the tornado was on us. That was my greatest fear." - ENGLISH/DRAMA TEACHER

" I was watching the sky and the lightning seemed to get worse. The minutes went by and it at first had been going vertically and slowly it started to go on angles.

The black cloud looked like it was about 2½ miles away from the school. As I watched, the lightning came concentrated into the middle of the cloud and began going on angles until it was horizontal.

For a few seconds, I didn't know that the shrinking cloud was forming a tornado funnel. The funnel was a whitish-grey color more in the shape of a column than it was a funnel. I realized it was a tornado when I saw air currents begin to swirl. At first I was not afraid. Instead I was fascinated that you could really see air currents in it.

I went to the main office to get the principal, but the office was locked and everyone was gone. Just as I started to move the drama cast started to rehearse a song in the auditorium, so I headed for the auditorium.

I walked down the aisle past 24 rows of seats to one of my friends in the second row and said, 'Hi Paul, have you ever seen a tornado?' He said 'Ya' and put his arm up on the back of a chair like he's getting ready for a long conversation. I said 'neat, there's one across the street'. He looked up at me. The kids up front and to the side looked up at me. Then thay all stood up and started to walk out. They got about ½ way out and started running.

All the kids were yelling 'Hey neat, look at that' and things like that. All of a sudden everyone was dead silent for about 4 seconds. Then everyone started screaming and yelling at once. Julie yelled 'Get to A-1'. I said 'Get to the southwest corner'. Mr. Heath turned around and yelled, 'Go to the main hall'. So all the cast started to rush out of the doors and promptly got stuck so they had to wait and go slow and go out 1 or 2 at a time."

- STUDENT (SPOTTER)

" When we were warned about the tornado, we all ran to the door to look at it. I was about the last one to arrive there and I stood there very long until someone yelled from around the corner to get over there. The last thing I saw the tornado doing, was picking up my car which was parked out on the street.

I then ran around the corner and found everyone already lying along each side of the wall and some around the corner. I then ran to the intersection of the 2 halls and laid alongside the wall.

When it was all over, I was buried from the waist down in little pieces of gravel, boards and a lot of water from the lake across the street in the park."

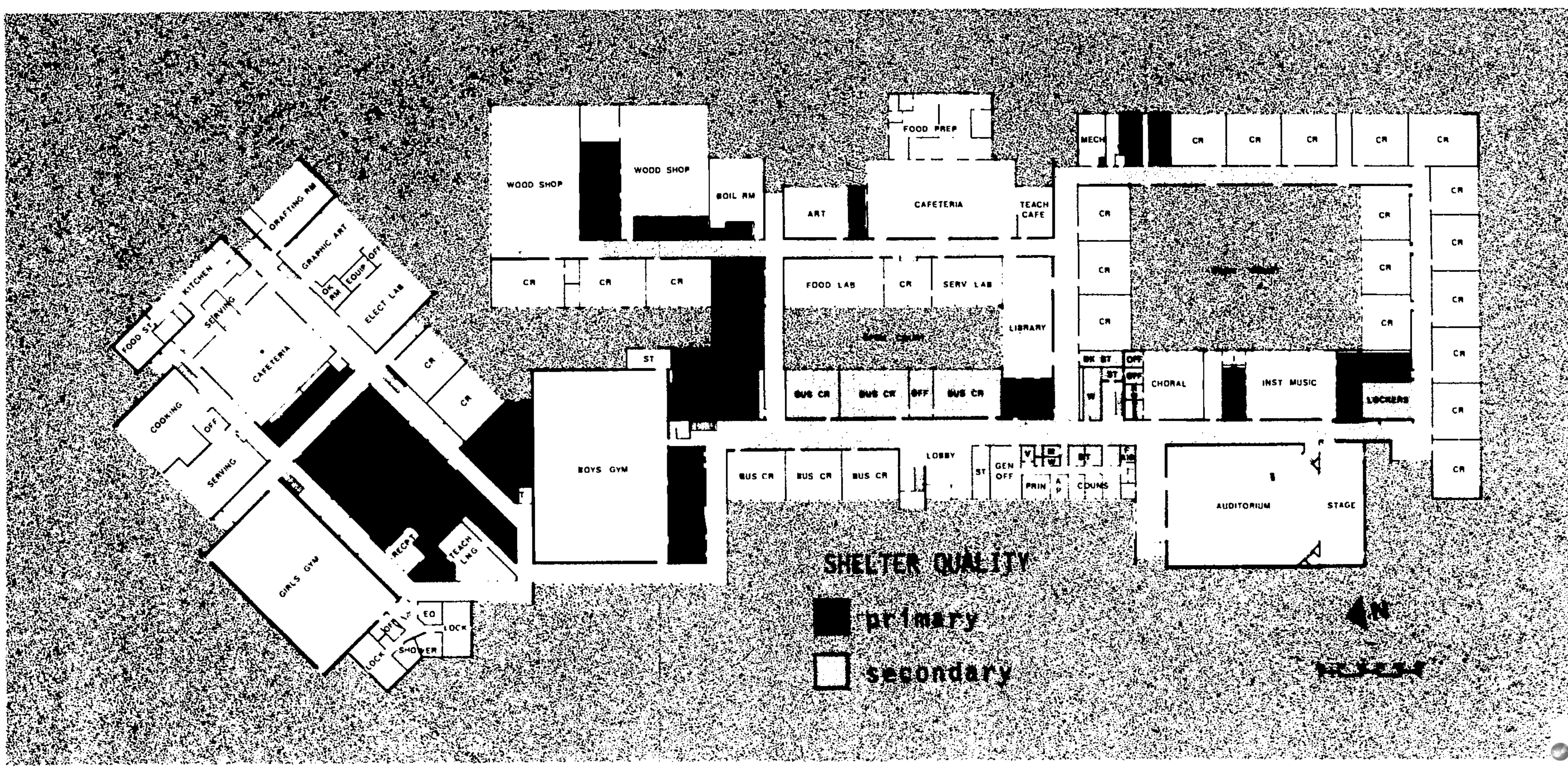
- STUDENT

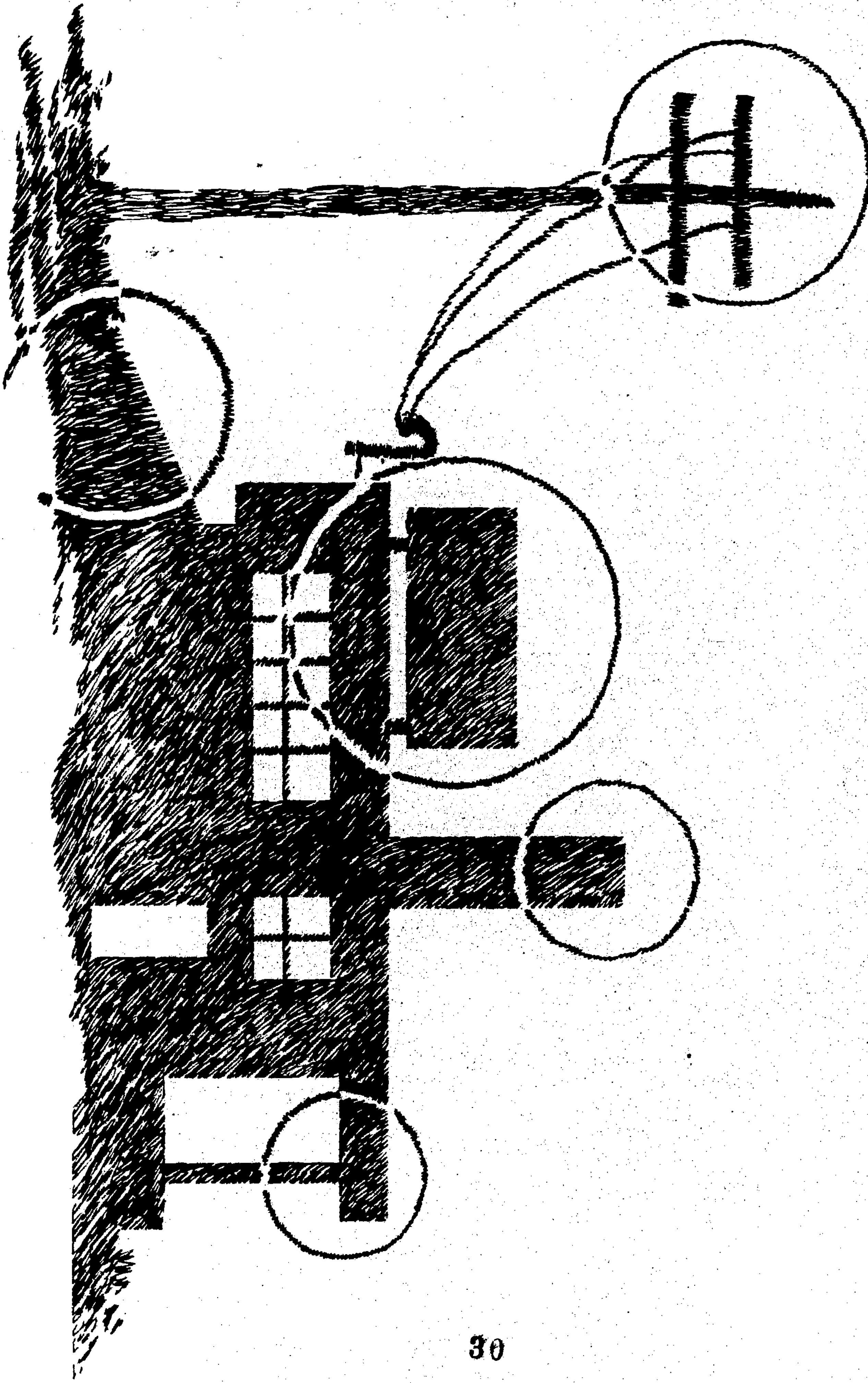
" The first place I ran to was this little cubbyhole right in front of the girl's restroom door. If I had stayed there, I would have been splattered across the hall, because it blew so hard it almost came off its hinges. For some reason, which I can not account for, I dived across the hall right after the lights went out and got to the other side of the hall just as the front doors were breaking.

I kept my eyes open which was stupid on my part. I was looking down at the floor rather than out and I could see big chunks of wood and debris flying down the hall by my feet. It was incredible."

- STUDENT

3.13





This procedure is designed to assist in a systematic review of a building to find the locations of the best available shelter space against high winds. It is not intended to imply that these spaces guarantee safety during a storm, but that they are the safest available in the building.

There are some facilities such as *lightweight modular houses, offices and classrooms which must be presumed to be death traps. THEY SHOULD BE EVACUATED!*

ADVANCE PREPARATION

Obtain the following equipment; compass, flashlight and tape measure.

Know tornado history for the geographic area. Consult the nearest National Weather Service office.

Obtain plans of the building for each floor. Ideal plans are small, to scale, with sufficient detail. If the drawings are not available, have someone prepare a simple, yet accurate drawing of each floor. Check the drawings against the actual building. Do not assume accuracy.

SPACE REQUIREMENTS

The space per person depends on the size of the people and their degree of mobility. Small children require only 4 sq. ft./person. Usually 6 sq. ft./person is adequate for adults. However, nursing home or hospital patients will require much more space.

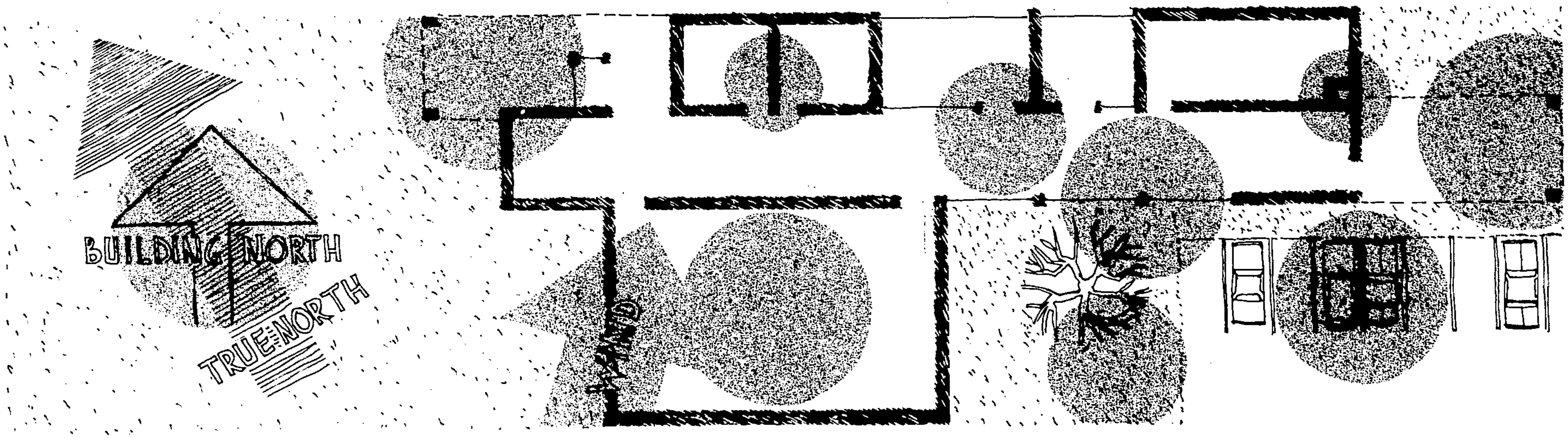
RECORD AND TEST

A plan is almost worthless if it is not tested and understood by the people it is intended to protect. A good plan has the following features;

a. It is recorded and shared with others so that all know what to do and where to go.

b. It identifies 1 or more spotters who are responsible for prompt, accurate visual identification of an approaching storm. The National Weather Service will provide training.

c. It contains a prompt, clear warning alarm that is readily understood by all.



1. EXTERIOR SURVEY

Establish true (magnetic) north. Use a compass or compare the building to an accurate map of the locality. Place a north arrow on the floor plans of the building. Do not confuse true north with *BUILDING NORTH*, a direction used to simplify the drawings.

Observe completely around the building, looking for and recording the location of;

a. potential missiles such as site equipment, nearby buildings, automobiles and other debris, especially on the south and west sides.
b. ground embankment against the building.
c. mechanical equipment on the roof.
d. electrical service entrance.
e. high building elements such as chimneys, higher portions of the building.
f. changes in roof level.

Take a long look from each direction, particularly from the south and west, noting building entrances, windows and construction features.

2. AVOID!

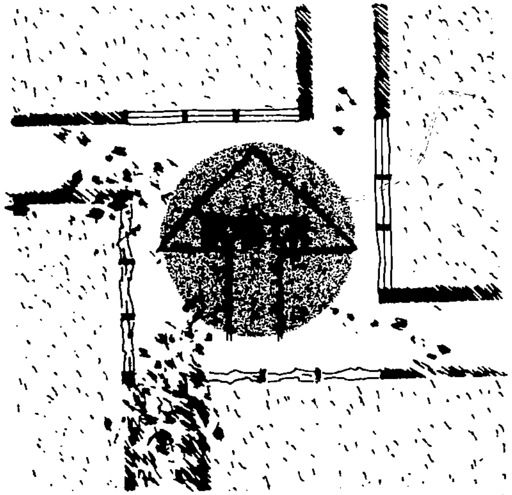
Carefully identify the following spaces as the most hazardous location, *the spaces to avoid!*

Avoid locations where roofs are likely to be removed. The roof may fall in on the occupants. Missiles also have direct access to the interior. The portions of roofs that are most likely to be removed are;

a. the windward edges (usually south and west).
b. the long spans.
c. the portions with loadbearing wall supports.
d. the portions with overhangs on the windward sides.

Avoid exterior walls that are most likely to be partially or completely destroyed. The most likely damage will probably occur in the following order, to the;

a. south wall
b. west wall
c. east wall
d. north wall



AVOID!

Avoid those corridors that may become *WIND TUNNELS.* Examination of corridors after tornadoes revealed much debris and evidence of very high speed. This was found in corridors whose exterior doors exited directly (no turns) to the following directions, *in order of severity of wind tunnel effect;*

a. south
b. west
c. east
d. north

Avoid those locations with *WINDOWS facing the likely storm direction.* Assume that the windows will blow *IN* on the south and west and occasionally on the east and north sides of the building.

Avoid whenever possible portions of buildings that contain loadbearing walls. If the wall collapses the roof of floor will fall in.

3. CONSIDER - but not necessearily select..

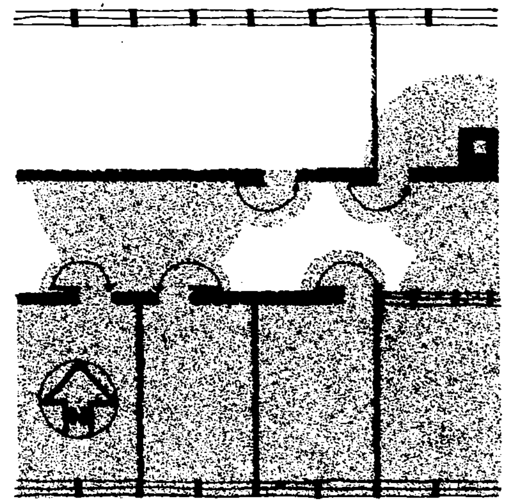
Examination of building failures after high winds reveal a pattern of spaces still remaining after the storm. These are the spaces to consider for occupancy.

Consider the *LOWEST FLOOR.* If the building has a basement, or a partial basement, it is probably the safest space in the structure.

Consider the *INTERIOR SPACES.* These are spaces that have no walls on the exterior of the building. However, avoid interior spaces that have large spans.

Consider the *SHORT SPANS.* It is difficult to find one space that will offer a high degree of protection to all of the building occupants with the exception of a basement. Therefore, seek out a number of smaller spaces.

Consider the portions of buildings that are supported by *RIGID STRUCTURAL FRAMES* such as steel, concrete or wood, rather than those portions that have loadbearing walls.



4. REFINE

It is essential that spaces selected are the very best available. Often poor (relatively hazardous) spaces exist within generally safe areas. These poor spaces must be avoided or occupied as a last resort.

Avoid spaces that are opposite doorways or openings into rooms that have windows in the exterior walls, particularly facing south or west.

Avoid interior locations that contain windows such as display cases, transoms above doors and door sidelights.

Avoid interior locations under skylights or clearstories.

Avoid locations where interior doors swing. When the storm hits, the doors are likely to swing violently.

Avoid spaces within the falling radius of higher building elements such as chimneys or upper walls enclosing higher roof areas. Assume that the falling radius is approximately equal to the height of the higher building element above the roof.

5. OTHER CONSIDERATIONS

Often the best available shelter spaces in the building can *NOT* be occupied during emergencies due to various legitimate reasons. Consideration of the following questions will identify this possible conflict.

What portion of the space is usable? Permanent equipment and furniture reduce the usable space.

Which good spaces are often unaccessible? Many fine spaces are locked with few people having keys.

Which good spaces are unsuitable for occupancy due to operational reasons? Many secure spaces offer excellent protection but are operationally *not good* to retain security over records, equipment or money.

Where is the building first-aid kit or medical supplies? They should be in one of the safest spaces.

Would protection levels increase significantly and time to shelter decrease significantly if people were jammed in at lower square foot per person ratios? This is a valid alternative to lower quality protection with more adequate space per person.